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MEMORANDUM REPORT ARBRL-MR-03183

A SIMPLE QUADRATURE FORMULA FROM  
SIMPSON'S RULE APPLICABLE  
FOR ODD OR EVEN  $n$

Noel H. Ethridge

June 1982



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND  
BALLISTIC RESEARCH LABORATORY  
ABERDEEN PROVING GROUND, MARYLAND

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER MEMORANDUM REPORT ARBRL-MR-03183	2. GOVT ACCESSION NO. AD-A116 867	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A SIMPLE QUADRATURE FORMULA FROM SIMPSON'S RULE APPLICABLE FOR ODD OR EVEN n		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Noel H. Ethridge		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Ballistic Research Laboratory ATTN: DRDAR-BLT Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L161102AH43
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research & Development Command US Army Ballistic Research Laboratory Aberdeen Proving Ground, MD 21005		12. REPORT DATE June 1982
		13. NUMBER OF PAGES 16
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Distribution unlimited, approved for public release.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Simpson's Rule Quadrature Formula Numerical Integration		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A simple quadrature formula is derived using Simpson's One-Third Rule that applies for an odd or even number of subdivisions, and whose coefficients of the ordinates are unity except near the ends of the integration range. Error estimates are made as is done for Simpson's Composite Rule. To apply the formula, two additional ordinates must be available, those at the midpoint of the intervals at each end of the integration range.		

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## I. INTRODUCTION

Simpson's One-Third Rule in composite form is one of the most frequently used of the simpler quadrature formulas for equidistant ordinates. The analysis of error in the rule has been extensive, and relations are available for estimating the error.<sup>1,2</sup> The rule is applicable only for an even number of equidistant subdivisions of the range of integration, and the coefficients of the ordinate values away from the endpoints differ by a factor of two.

The purpose of this report is to present a composite formula generated from Simpson's Rule that applies for either an odd or even number of subdivisions of the range of integration, and whose coefficients of the ordinates are unity except near the ends of the integration range. Having coefficients of unity over most of the integration range is an advantage when the ordinates correspond to measurements with errors, because the errors are weighted equally in the integration process. Amplification of roundoff noise in computed ordinates will be minimized also. However, to obtain these advantages, two additional ordinates must be obtained and utilized.

## II. DEVELOPMENT OF THE FORMULA

Simpson's One-Third Rule in composite form is:

$$I = (h/3)(y_0 + 4y_1 + 2y_2 + \dots + 2y_{n-2} + 4y_{n-1} + y_n) + E$$

where:  $I$  = value of integral

$y_0, \dots, y_n$  = ordinate values at intervals of  $h$  on the abscissa

$E$  = error term

Consider a range of integration divided into an odd number of equidistant intervals of width  $h$ . The rule can be applied to the range of an even number of intervals with ordinates of  $y_0$  through  $y_{n-1}$ . The rule also can be applied to the range with ordinates of  $y_1$  through  $y_n$ . If the two results are added the sum is twice the value of the desired integral less the values of the integral for the intervals between  $y_0$  and  $y_1$  and between  $y_{n-1}$  and  $y_n$ . If a value for the ordinate at the midpoint of each of these end intervals can be obtained, then Simpson's Rule can be applied to obtain the integral values for the end intervals. Adding these values to the previously obtained sum from the application of the

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<sup>1</sup> J. B. Scarborough, Numerical Mathematical Analysis, 4th Edition, The Johns Hopkins Press, Baltimore, Maryland, 1958.

<sup>2</sup> R. W. Hamming, Numerical Methods for Scientists and Engineers, McGraw-Hill Book Company, New York, New York, 1962.

composite formula, the following result for the full range of integration for an odd number of subdivisions of width  $h$  is obtained:

$$\begin{aligned} 2I = & (h/3)(y_0 + 4y_1 + 2y_2 + 4y_3 + \dots + 2y_{n-3} + 4y_{n-2} + y_{n-1}) \\ & + (h/3)(y_1 + 4y_2 + 2y_3 + \dots + 4y_{n-3} + 2y_{n-2} + 4y_{n-1} + y_n) \\ & + (h/6)(y_0 + 4y_{1/2} + y_1) + (h/6)(y_{n-1} + 4y_{n-1/2} + y_n) + E \end{aligned}$$

After combining terms, the formula becomes:

$$I = h \left[ (1/4)y_0 + (1/3)y_{1/2} + (11/12)y_1 + y_2 + y_3 + \dots + y_{n-3} + y_{n-2} + (11/12)y_{n-1} + (1/3)y_{n-1/2} + (1/4)y_n \right] + E \quad (1)$$

All coefficients except for the end points and the midpoints of the end intervals are  $11/12$  or one.

Now consider a range of integration divided into an even number of equidistant intervals of width  $h$ . Here Simpson's Rule can be applied to the entire range of integration. It can also be applied to the range beginning with the ordinate  $y_1$  and ending with the ordinate  $y_{n-1}$ . If the results are added the sum as before is twice the desired value for the integral less the integral values for the intervals from  $y_0$  to  $y_1$  and from  $y_{n-1}$  to  $y_n$ . Assuming that the ordinate for the midpoint of each end interval is available, the integral values for the end intervals can be obtained by applying Simpson's Rule, and the formula for the entire integration range becomes as follows:

$$\begin{aligned} 2I = & (h/3)(y_0 + 4y_1 + 2y_2 + \dots + 2y_{n-2} + 4y_{n-1} + y_n) \\ & + (h/3)(y_1 + 4y_2 + 2y_3 + \dots + 2y_{n-3} + 4y_{n-2} + y_{n-1}) \\ & + (h/6)(y_0 + 4y_{1/2} + y_1) + (h/6)(y_{n-1} + 4y_{n-1/2} + y_n) + E \end{aligned}$$

After terms are combined the formula for  $I$  is found to be identical to that presented in Equation 1. Therefore Equation 1 applies for both even and odd  $n$ .

Because the integral for the two end intervals is more accurately determined through use of one-half width intervals in the computation, the error for the full integration range will be somewhat less than that calculated for Simpson's Rule for  $n$  subdivisions. However, the reduction is small, and becomes less as the number of subdivisions is increased, since the proportion of the range determined with less error becomes smaller as the number of subdivisions increases. Therefore error estimates for the formula in Equation 1 are made as for Simpson's Composite Rule, ignoring the one-half interval ordinates.

In summary, the quadrature formula presented in Equation 1 applies for an odd or even number of equidistant subdivisions of the range of integration, and provides coefficients of unity or near unity except for the two ordinates at each end of the integration range. The error estimate can be made as is done for Simpson's Composite Rule. However, to apply the formula, two additional ordinates must be available: those at the midpoint of the intervals at each end of the integration range.

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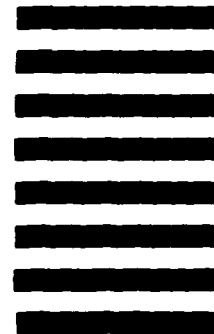


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